Feb. 22, 1955 G. HERZOG 2,702,865

ELECTRON MULTIPLIER

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Fig. 1.

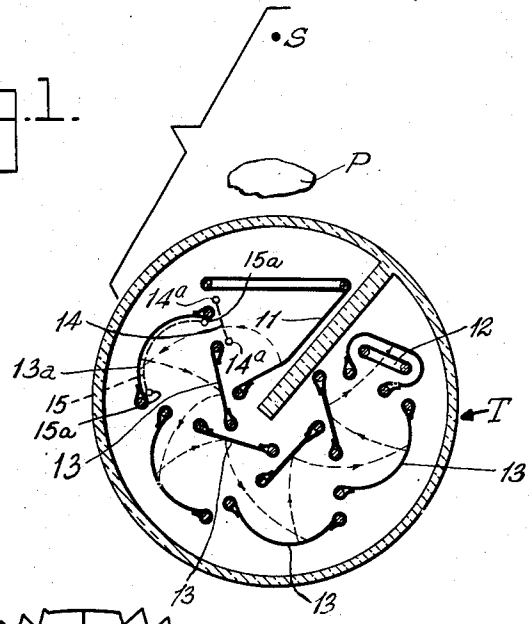
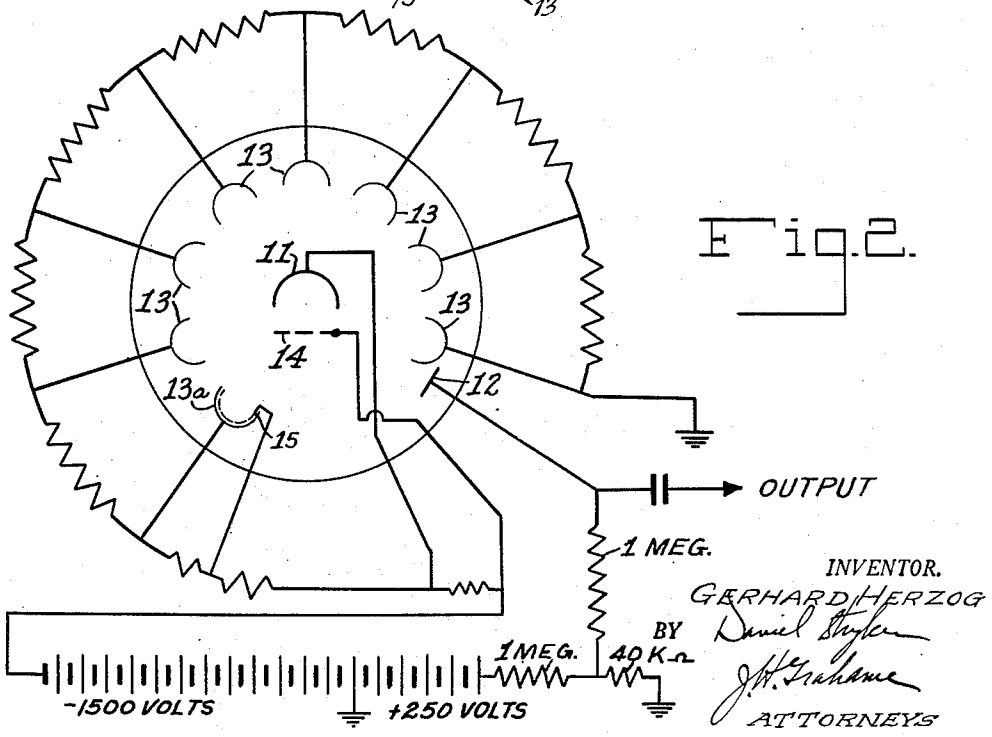


Fig. 2.



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ELECTRON MULTIPLIER

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6 Claims. (Cl. 250—207)

This invention relates to electron multipliers of the photocell type, usually termed multiplier tubes.

Such multiplier tubes ordinarily comprise a vacuum envelope containing a photocathode, an anode, and one or more so-called target electrodes or dynodes between the cathode and the anode. As distinguished from the simple photocell containing only a cathode and an anode, the photo electrons emitted by the cathode by reason of the radiation directed thereagainst, instead of passing to the anode, pass to a target electrode or dynode which is maintained at a positive potential with respect to the cathode. These primary electrons from the cathode cause the emission of secondary electrons in greater number from the target electrode or dynode, the total number of electrons discharged from the target electrode being greatly in excess of the primary electrons striking the electrode, thereby effecting a multiplication of the original electronic impulses. By setting up a series of such target electrodes or dynodes at successively higher positive potentials, the electron stream can be caused to impinge successively on the electrodes, the electron stream being greatly increased by its contact with each target electrode, thereby obtaining a final multiplication factor which is a function of the factor S of each target electrode and of the number n of target electrodes, i. e.,

$$M=S^n$$

Such multiplier photocells have found a number of uses, a typical use being the measurement of radiation emitted from a phosphor such as naphthalene or scheelite when subjected to penetrative radiation such as gamma rays. In such a situation, the gamma rays striking the phosphor cause scintillations in the ultraviolet and near visible range of the spectrum which are observed by the photocathode. While the observed scintillations may be of small magnitude, the photocell multiplies the scintillations or the electrons produced thereby to an extent as to be amplified and measured by more conventional and relatively simple apparatus such as an amplifier in combination with a pulse height discriminator and a rate meter. A typical apparatus is described in Nucleonics, January 1949, pp. 16 et seq.

In this application and in other applications, such multiplier photocells are characterized by a so-called "dark current" which causes the emission of electrons internally within the cell, this emission interfering with the use of the cell, and contributing to undesirable "noise" therein. At times this noise exceeds the magnitude due to the photoelectrons and prevents measurements of any type.

There are two causes of the dark current. One cause is internal or external leakage between the cathode and the anode. This leakage of the current is not considered to present a difficult problem and can usually be corrected by mounting the cathode terminal as far as possible from the anode terminal. A second and perhaps the principal cause is the thermionic emission inherent in the photocell. At room temperature, this emission by itself may be of a magnitude in excess of the radiation or emission being measured. The thermionic emission can be reduced by cooling the cell to a temperature of about —40° C. Obviously this is not a practical solution. Coincidence circuits have been proposed as a solution but they require the use of more than one photocell and added circuits. Since the thermionic emission is roughly proportional to the photocathode area, it can be reduced by reducing the cathode area. But, this is not always desirable.

The present invention has as its major object the provision of a novel photocell wherein the thermionic emission is substantially eliminated in a practical manner without resorting to any of the above devices.

A further object of the invention is the provision of a photocell wherein the photocathode can be made as large as desired without a prohibitive increase in thermionic emission and a resultant noise.

Still a further object of the invention is the provision of a novel method of operating a photocell wherein the noise due to thermionic emission is substantially eliminated.

Other objects of the invention will appear from the following description and claims taken in connection with the attached drawing which illustrates an embodiment of the invention showing a photocell in combination with a phosphor and a source of penetrative radiation.

In brief, the present invention can be described as involving a method and means whereby thermionic electrons generated within a multiplier photocell are suppressed therein and their flow to the respective target electrodes is halted. Preferably this is accomplished by the use of one or more grid suppressors in front of one or more target electrodes, the grid or grids being impressed with a voltage which suppresses the thermionic electrons and passes the photo electrons which it is desired to measure.

The invention can be illustrated by reference to the drawings wherein a practical application of a multiplier photocell is illustrated diagrammatically. In the drawing, Fig. 1 is a representation of a scintillometer using a photo-multiplier tube which is modified according to the present invention, and is shown in transverse cross section, and Fig. 2 is a schematic diagram of a suitable circuit for the photo-multiplier tube. In Fig. 1 S is a source of penetrative radiation such as gamma rays, P is a so-called phosphor such as naphthalene or synthetic or natural calcium tungstate which under the bombardment of gamma rays, eectrons, and alpha particles emits radiation in the near visible and ultraviolet ranges of the spectrum and T is a diagrammatic representation of a multiplier photocell.

Photocell T, of generally conventional type as shown at page 79 of Photoelectric Cells by Sommer (Chemical Publishing Company, Inc., 1947), includes a photocathode **11** exposed to radiation from phosphor P, an anode **12**, arranged to be connected to a suitable amplifying means and measuring means, and series of target electrodes or dynodes **13** between the cathode and the anode. Each of said target electrodes has a secondary emitter surface or sensitized side as is customary in conventional types of photomultiplier tubes.

In operation, phosphor or "luminophor" P is exposed to bombardment of radiation from source S, the phosphor then emitting radiation which is directed onto photocathode **11**, causing the emission of electrons which pass from target electrode to target electrode in the cell by reason of the successively higher potentials impressed on the respective electrodes, pulses being finally obtained at anode **12**. The number of the pulses constitutes a measure of the intensity of the original penetrative radiation.

The present invention contemplates the use of a velocity filter grid **14** which is supported on a pair of support rods **14***a* between photocathode **11** and target electrode **13***a*, the grid being maintained at a negative voltage with respect to the photosensitive or photo-emissive cathode **11** (see Fig. 2), that voltage being substantially equal to the average voltage of the emitted thermionic electrons. As in conventional practice, a resistor or a series of individual resistors, are connected in shunt across the direct current supply source as shown in Fig. 2. A special connection is, however, shown in this figure connecting the filter grid **14** to the most negative terminal of the resistor system; thus to provide a source of direct voltage between cathode **11** and the filter grid **14**, with the latter connected to the negative pole of the main supply source to polarize it negatively with

respect to the cathode. Thus the thermionic electrons will be hindered from passing the grid while the photoelectrons with their higher energy will pass through the grid and through the remainder of the multiplier. Stated otherwise, the grid affords electrical means whereby a discrimination can be effected between the photoelectrons and the thermionic electrons. One of the support rods **14***a* may be conductively extended, in a direction corresponding to downward in the drawing, through the press and base of the tube to an appropriate one of its terminal pins, whereby this support rod may serve to carry an externally applied polarizing potential to the filtering grid **14**. Since the base, the press and the terminals are included among conventional parts of the tube which may be made in accordance with the prior art and do not of themselves constitute features of the present invention, they are not shown or described in detail herein to simplify the drawing and the disclosure.

If desired, this principal of such a grid in front of a dynode may be extended to other than the first dynode **13***a*, the voltage on each such grid being necessarily different. Thus a velocity filter grid, like the grid **15** shown in Fig. 1, may be mounted on a pair of support rods **15***a* closely adjacent and parallel to the secondary emitter surface of the dynode **13***a* athwart the path between it and the second dynode, i. e., in front of the second dynode. However, such use of a grid in front of other than the first dynode is not necessary to a material reduction of noise since the electrons from the other dynodes are subject to less overall multiplication and, therefore, are of less effect.

The action of the grid or grids may be explained as follows: The electrons which leave a metal surface by thermionic emission have an average kinetic energy of $2kT$ where k is Boltzmann's constant or 1.381×10^{-16} ergs per degree centigrade which is the same as 7/80,000 electron volts per degree centigrade, and T is the temperature in degrees Kelvin (see pages 112–113 and 708 of Introduction to Modern Physics, 3rd Edition, by Richtmyer and Kennard, published by McGraw-Hill Book Co., 1942). Thus, for a surface at room temperature, the average kinetic energy of the thermionic electrons is 0.05 electron volt.

On the other hand, electrons are emitted due to the action of the photons which are released from the phosphor under the bombardment of the penetrative radiation. The energy of these photons can be determined from the wave length according to the formula

$$\text{Energy}=\frac{12340}{\lambda}eV$$

where λ is the wave length of the photons in Angstrom units. The photoelectric electrons will lose an energy equal to the work function of the metal and will lose additional energy in collisions before they manage to leave the cathode. They will have a maximum possible kinetic energy outside the cathode which is given by

$$E_{max}=\frac{12340}{\lambda}-W$$

where W is the work function of the cathode material.

According to available authorities, the wave length of the fluorescent light of naphthalene is between 3200 and 4200 A. Assuming an average value of 3700 A, these quanta will produce electrons of an energy of $3.3-W$ electron volts. The work function of cesium which is widely used as one of the components of a photo cathode surface is 1.9 volts. Therefore, the maximum kinetic energy of the photo electrons emerging from a cesium surface due to the action of light with a wave length of 3700 A would be 3.3—1.9 or 1.4 electron volts. However, the average energy of these photo electrons would be about one-half this value or 0.7 electron volt (see Figure 3.1 of Photoelectric Phenomena by Hughes and DuBridge, Published 1932 by McGraw-Hill Book Co., New York, N. Y.), which is much greater than the average energy of thermionic electrons.

By reason of this difference in energy, the photo electrons will be able to pass a grid of predetermined negative voltage with respect to the cathode whereas the thermionic electrons will be hindered from passing. The voltage of the grid should be equal to the average voltage of the emitted thermionic electrons.

Obviously many modifications and variations of the invention as hereinabove set forth may be made without departing from the spirit and scope thereof and only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. A multi-electrode discharge device comprising in a vacuum envelope a photo-emissive cathode and an anode at opposite ends of a path of electron travel starting at the cathode, at least one intermediate target electrode positioned along said path between the cathode and anode, said target electrode having a sensitized side on which it receives primary electrons which reach it moving along a portion of said path in certain incident directions and from which it responsively emits secondary electrons along another portion of said path in different directions than the incident ones, a velocity-filter-grid positioned athwart said path, said grid being the electrode of the device which is nearest-adjacent the side of the cathode which faces along said path, and terminal means for applying uniformly to said grid a potential which is negative with respect to the cathode to establish a voltage difference therewith equal to the average velocity of thermionic electrons emitted from the cathode.

2. A photo-multiplier discharge device comprising in a vacuum envelope a cathode having a photo-emissive surface, an anode at the end of a path of electron travel starting at said surface, an intermediate target electrode having a secondary-emitter surface positioned to receive photo-electrons from said cathode surface arriving in certain incident directions along a portion of said path and to give off secondary electrons along another portion of said path in different directions than the incident ones, a velocity-filter grid positioned athwart said path intermediate said surfaces of the cathode and the target electrode, and terminal means for applying uniformly to said grid a potential which is negative with respect to the cathode to establish a voltage difference therewith to prevent any significant transfer from the cathode to the target electrode of electrons having less than a predetermined average initial velocity.

3. A photo-electric device for translating light scintillations into electrical pulses with a minimum of background thermal noise comprising a vacuum envelope containing a photo-emissive cathode having a photo-emissive surface facing along a path of electron travel, said surface being subject to the spurious emission of thermionic electrons, an electrode for collecting electrons reaching the end of said path to provide an output current, a velocity-filter grid positioned athwart said path, and a voltage source connected between said grid and cathode for polarizing the former negatively with respect to the latter to prevent a larger percentage of the thermionic-electrons than of the photo-electrons emitted by the cathode from moving through the grid in moving along said path.

4. A multi-electrode discharge device comprising in a vacuum envelope, a cathode having a photo-emissive surface facing along a path of electron travel, an electron-collecting anode at the end of said path, an intermediate target-electrode having a secondary emitter surface positioned to receive electrons from said surface of the cathode and to give off secondary electrons in directions along said path toward the anode, a first velocity-filter grid positioned athwart said path, said grid being the electrode of the device which is nearest adjacent to said surface of the cathode, first terminal means for applying to said grid a potential which is sufficiently negative with respect to the cathode to prevent a larger percentage of the thermionic-electrons than of the photo-electrons emitted from the cathode to pass through the grid to said first target electrode, a second velocity-filter grid positioned athwart said path, said second grid being the electrode of the device which is nearest adjacent to said secondary emitter surface, and second terminal means for applying to said second grid a potential which is sufficiently negative with respect to the target electrode to prevent a larger percentage of the thermionic-electrons than the secondary-electrons given off thereby to pass through the second filter grid in moving along said path.

5. Electrical apparatus comprising: a photoelectric device including within an hermetically sealed envelope a photo-emissive cathode positioned to receive light through a wall of the envelope from an external source thereof, an anode for collecting electrons moving along a path which extends from said cathode to said anode

and a velocity filter means positioned athwart said path in spaced and insulating relationship to said cathode; and a voltage source connected between said cathode and said velocity filter means for establishing a negative electric field therebetween to impede the progress along said path of more thermal than photo-electrons.

6. In a scintillometer the improvement wherein the photo-electric device comprises a photo-emissive cathode for receiving light from the luminophor of the scincillometer, an anode for collecting electrons moving along a path which extends from said cathode to said anode, and means, including a velocity-filter grid extending athwart said path in a region thereof intermediate said cathode and anode and a source of direct voltage with its positive and negative poles respectively connected to said cathode and grid, for more greatly reducing the

number of thermal electrons which can move through said region along said path than of other, higher-energy electrons.

References Cited in the file of this patent

UNITED STATES PATENTS

1,898,080	Culver	Feb. 21, 1933
2,135,615	Farnsworth	Nov. 8, 1938
2,227,030	Schlesinger	Dec. 31, 1940
2,234,801	Gorlich	Mar. 11, 1941
2,256,300	Van Mierlo	Sept. 16, 1941
2,305,179	Lubszynski	Dec. 15, 1942
2,401,734	Janes	June 11, 1946
2,517,404	Morton	Aug. 1, 1950